DERMAL DENTICLES AND MORPHOMETRICS OF THE SAILFIN ROUGHSHARK *OXYNOTUS PARADOXUS* (ELASMOBRANCHII, OXYNOTIDAE), WITH COMMENTS ON ITS GEOGRAPHIC DISTRIBUTION

by

José Manuel N. AZEVEDO, Fernando L. SOUSA & João M.M. BRUM (1)

ABSTRACT. - The dermal denticles of the sailfin roughshark *Oxynotus paradoxus* are described and illustrated with SEM pictures, based on two specimens captured at the Azores. The flank denticles are similar to those of *O. centrina*, with a central cusp flanked by two smaller lateral cusps, rising from the lateral ridges, and a secondary median cusp posterior to the main one. Differences in squamation between both species are described. Body proportions of the Azorean specimens are given and found to be consistent with those reported by previous authors. The published information shows depth of capture to have a mode at 570 m. A bathybenthic habitat has been suggested, with spring reproductive migrations to the continental shelf. The presence of this species in the Azores and Mid-Atlantic Ridge represents a significant westward extension of its previously known geographic distribution, the continental shelf and upper slope of the north and eastern Atlantic. It is possible that *O. paradoxus* is continuously distributed along the north-eastern Atlantic floor, deeper than presently known. Alternatively, separate slope and ridge populations may exist.

RÉSUMÉ. - Denticules cutanés et morphométrie de l'humatin, *Oxynotus paradoxus* (Elasmobranchii, Oxynotidae), et commentaires sur sa distribution géographique.

Les denticules cutanés de l'humatin, *Oxynotus paradoxus*, prélevés sur deux exemplaires capturés aux Açores, sont décrits et illustrés par des photographies prises au microscope électronique de balayage. Les denticules des flancs sont identiques à ceux d'*O. centrina*, avec une grande cuspide centrale, deux cuspides latérales plus petites et une cuspide médiane secondaire, postérieure à la principale. Les différences entre les denticules des deux espèces sont présentées. Les proportions morphologiques des exemplaires des Açores sont données ; elles sont comparables à celles qui ont été fournies par d'autres auteurs. La profondeur de capture signalée dans la littérature est en moyenne de 570 m. Un habitat bathybenthique a été suggéré, avec des migrations reproductrices vers le plateau continental au printemps. La présence de cette espèce aux Açores et sur la dorsale atlantique représente une extension importante vers l'ouest de sa distribution géographique: les plateaux continentaux et les talus de l'Atlantique Nord-Est. Il est possible que *O. paradoxus* ait une distribution continue dans l'Atlantique Nord-Est, à des profondeurs supérieures à celles qui sont connues actuellement. Dans le cas contraire, des populations séparées sur les plateaux continentaux et la dorsale peuvent exister.

Key-words. - Oxynotidae - *Oxynotus paradoxus* - ANE - Dermal denticles - Distribution - Depth range.

Three species of the deep-water shark genus *Oxynotus* are known from the Atlantic (Cadenat and Blache, 1981; Compagno, 1984; Yano and Matsuura, 2002): *O. centrina* (Linnaeus, 1758), from the Mediterranean, eastern north Atlantic and the tropical east Atlantic, from Angola to the west coast of South Africa; *O. paradoxus* Frade, 1929, from the eastern north Atlantic; and *O. caribbaeus* Cervigon, 1961, from the Caribbean Sea off Venezuela. Two other species of the genus occur outside the Atlantic, namely *O. bruniensis* (Ogilby, 1893) in South Australia, Tasmania and New Zealand and *O. japonicus* Yano & Murofushi, 1985, endemic to Japan.

Since it was described by Frade (1929) from a specimen caught off the coast of Morocco, *O. paradoxus* has been found in several places along the west-African coast, from the Canaries (Yano and Murofushi, 1985), Rio de Oro (Maurin and Bonnet, 1970) and Mauritania (Cadenat, 1961) to Senegal, Dakar and Cape Verde (Cadenat, 1950). It was also reported from the temperate-cold north Atlantic, from the French Basque coast (Frade, 1932; Harambillet *et al*., 1976), to the British Islands (Norman, 1932; Stephen, 1933; Fraser-Brunner, 1935; Tucker and Palmer, 1949; Rae and Lamont, 1960, 1962, 1963; Blacker, 1962; Rae and Pirie, 1967, 1968a, 1968b; Went, 1968; Wheeler and Blacker, 1969; O'Riordan, 1984; Mhurachú and O'Connor, 1987) and the North Sea (Brandes *et al*., 1954). Only recently has the species been reported form the Mid-Atlantic Ridge (Hareide and Garnes, 2001), and this is the first record from the Azores waters.

It has been collected from depths ranging from 265 to 800 m, with one isolated record (Went, 1968) at 92 m. Most records are from 500-600 m depth (mode 570 m).

(1) Departamento de Biologia, Universidade dos Açores, Apartado 1422, 9501-801 Ponta Delgada, PORTUGAL. [azevedo@notes.uac.pt]

As previously noted by Tucker and Palmer (1949, based on only 9 specimens), sex-ratio of the captures is biased towards the females: of the 36 specimens whose sex is mentioned in the literature, 23 are females and 13 are males. This fact, and the concentration of the capture records along the edge of the Atlantic Slope on the British Isles, led Tucker and Palmer (1949), following the discussion of Steven (1933), to suggest a reproductive migration towards the continental shelf in spring. Krefft (1955) also suggested a bathybenthic habitat, with seasonal migrations to shallower water.

Iconography and descriptions of *O. paradoxus* can be found in Frade (1929, 1932), Norman (1932), Krefft (1955), Compagno, (1981, 1984), and Quéro (1984), with further taxonomic treatment given by Bigelow and Schroeder (1957), Yano and Murofushi (1985), and Yano and Matsuura (2002).

The teeth of *O. centrina* and *O. paradoxus* were described by Ledoux (1970). Drawings and/or descriptions of the denticles of the former species were given by Kunstler and Chaine (1905), Lozano y Rey (1928), Tortonese (1956), and Cadenat and Blache (1981), and denticles from the body, head and fins were illustrated and described by Reif (1985). The denticles of *O. paradoxus*, however, have not previously been illustrated or described in detail.

MATERIAL AND METHODS

Dermal denticle description is based on two specimens captured in the Azores. The first, a female 628 mm TL, was captured on September 10, 1993, at a depth of approximately 600 m, near Banco Voador, southeast of Flores Island (37°35'N, 30°48'W), using bottom gill nets. A second specimen, a male 549 mm TL (Fig. 1), was brought to us in 1995, with the only indication of having been captured in the banks near Pico island. Both specimens were deposited in the collections of the Museum Carlos Machado, Ponta Delgada, Acores, with the catalogue numbers MCM 716 and MCM 955, respectively.

Skin samples of about 1 cm^2 were removed from the areas defined by Reif (1985). The samples were cleaned with a solution of KOH, dehydrated in ethanol, dried at 46°C for 24 h, and prepared for scanning electron microscopy (SEM) observation and photography. The SEM stubs and the complete set of photographs made are deposited in the Departamento de Biologia, Universidade dos Acores. Details of the dermal denticles in other areas were observed under a compound microscope. Denticle size was measured between the outer edges of the lateral cusps.

Body measurements followed Compagno (1984), except those made for comparison with the literature.

RESULTS

Species diagnosis

Of all Atlantic *Oxynotus*, only *O. paradoxus* has the posteriorly inclined first dorsal fin spine seen in our specimens. However, this characteristic is also present in *O. japonicus*. The two species can be distinguished, according to Yano and Matsuura (2002) by metric indexes and the shape of the spiracle. Table I shows the values given by those authors for each species, and the values of the present specimens. The characters of the Azorean specimens are within the range given for *O. paradoxus*, with the exception that the ratio between the interdorsal space and the length of the second dorsal base is higher than any other previously recorded. It should be noted, however, that the specimen is also larger than those analysed by Yano and Matsuura (2002).

Colour in fresh was uniform dark brown, the same mentioned by Frade (1929). It turns black after preservation, the colour reported for the species by Cadenat and Blache (1981).

Body measurements are given in table II, and compared

Figure 1. - *Oxynotus paradoxus* from the Azores (MCM 955, male, 549 mm TL).

	Yano *et al.*		Present work	
	O. japonicus	*O. paradoxus*	MCM 716	MCM 955
Interspace between 1st and 2nd dorsal / Length of 2nd dorsal base	1.2 - 1.5 (1.3)	1.7 - 1.9 (1.9)	2,3	1,9
Precaudal length / Snout tip to 1st dorsal spine	2.0 - 2.2 (2.1)	2.5-2.7 (2.7)	2,6	2,7
Spiracle shape	Oval	Round	Round	Round

Table I. - Diagnostic characteristics for the distinction between *Oxynotus paradoxus* and *O. japonicus*, according to Yano and Matsuura (2002, above) and Yano and Murofushi (1985, below, in parenthesis) and the corresponding values in the Azores specimens.

with those gathered from the literature. Most proportions are fairly consistent: the larger variations were found in the pelvic inner margin length, gill slit height, and internarinal space.

Dermal denticles

The denticles that cover most of the body are very similar to those of *O. centrina*: they have a central cusp flanked by two smaller lateral cusps, rising from the lateral ridges.

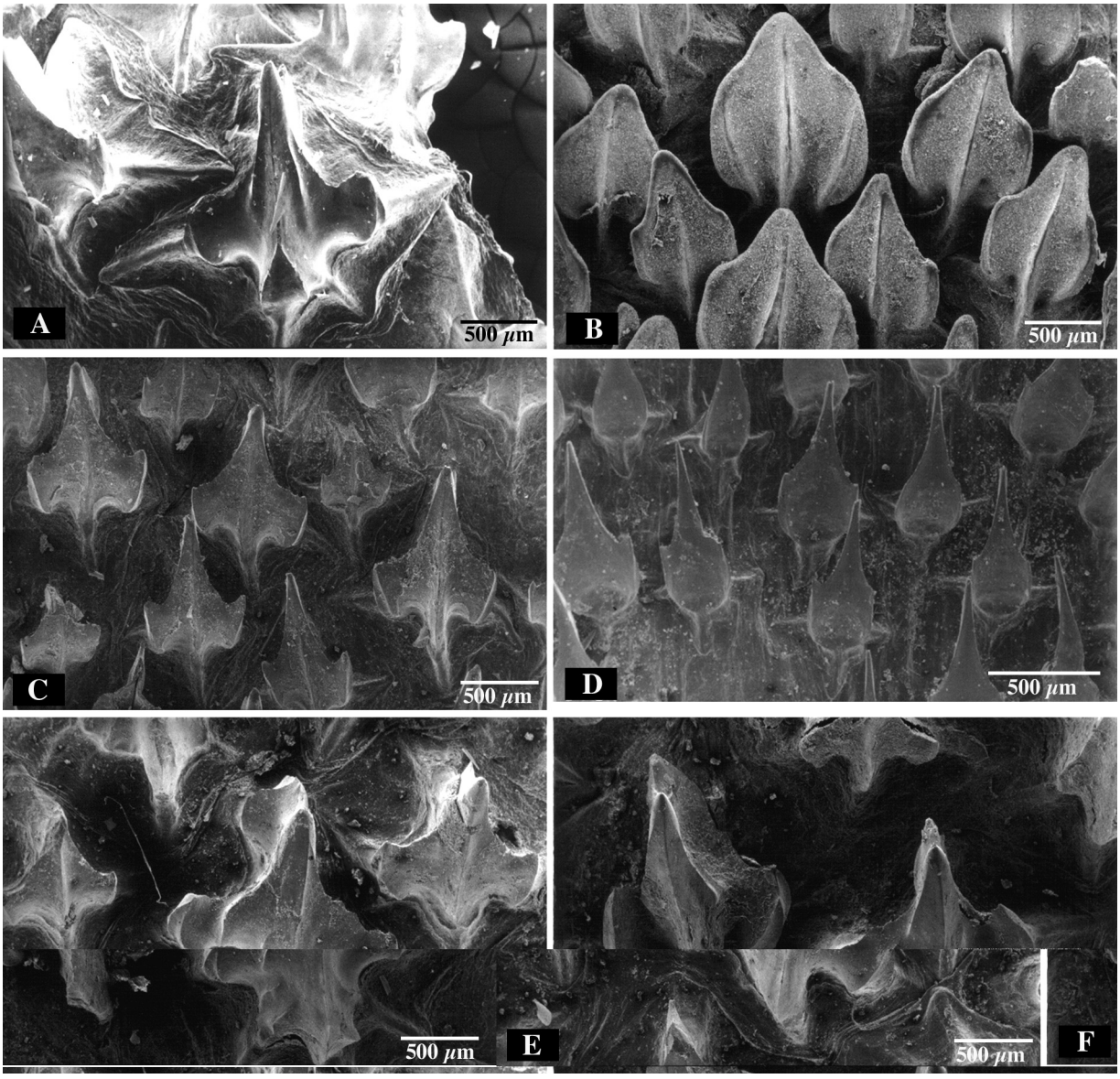

Figure 2. - *Oxynotus paradoxus*. SEM micrographs of dermal denticles. **A**: Flank; **B**: Ventral surface; **C**: Pectoral fin, anterior edge; **D**: Pectoral fin, trailing edge; **E**: Dorsal fin; **F**: Dorsal surface of the head.

Table II. - Body proportions of *Oxynotus paradoxus*, expressed as percentage of total length, in Azores specimens and from the literature. Yano *et al*. = Yano and Murofushi, 1985; Yano and Matsuura, 2002. Measurement codes follow Compagno (1984). F = female; M = male.

	Azores spm		Frade,	Krefft,	Maurin and Bonnet,	Yano
	MCM 716	MCM 955	1929	1955	1970	*et al*.
Sex	F	M	F	F	M	M
Total length (TOT, in mm)	638	549	780	810	595	508-555
Precaudal length (PRC)	76	81.1		84.5		78.6
Pre-second dorsal length (PD2)	56.9	58.5		64.8	58	56.4
Pre-first dorsal length (PD1)	17.2	17.1		21	15.1	16.6
Pre-first dorsal spine length	29.6	30.1				29.2
Head length (HDL)	21.2	18.8				18.4
Prebranchial length (PG1)	16.9	15.3			17.6	14.2
Prespiracular length (PSP)	10.3	10.4	9.7			9
Preorbital length (POB)	5.5	4.2	5.8		5.4	3.8
Prepectoral length (PP1)	18.3	19.9		18.5	20.2	19.6
Prepelvic length (PP2)	57.5	61.4		61.7	57.1	60.4
Snout-vent length (SVL)	61.9	63.8				65.4
Interdorsal space (IDS)	23.7	24.4	22.3	28.5		24.1
Dorsal-caudal space (DCS)	9.7	7.3	10.3	10.2		11.4
Pectoral-pelvic space (PPS)	31.2	39.3				41.8
Pelvic-caudal space (PCA)	11.6	10.6				9.9
Vent-caudal length (VCL)	39.7	34.1				
Prenanal length (PRM)	2.8	2.4		1.3		1.8
Preoral length (FOR)	6.1	5.6		4.7		5.8
Eye length (ElL)	3.3	5.1	3.8	3	4.2	4.5
Intergill length (ING)	4.2	4.2				
First gill slit height (GS1)	0.8	2		1.6		1.3
Second gill slit height (GS2)	1.1	22		2		1.3
Third gill slit height (GS3)	0.9	2.4		1.2		1.3
Fourth gill slit height (GS4)	0.9	2.4		0.7		1.1
Fifth gilt slit height (GS5)	1.1	2.4	1	0.6		1.1
Pectoral anterior margin (P1A)	18.8	18.9	16.6			15
Pectoral base (P1B)	6.1	5.3	5.6			49
Pectoral inner margin (P1l)	5.6	5.5				7.2
Pectoral posterior margin (P1P)	12.1	14.8	16.4			9.9
Pectoral height (P1H)	18.2	18.6		18.2	17.6	
Dorsal caudal margin (CDM)	23	20.2	20.9	17.6	22.7	22
Preventral caudal margin (CPV)	12.4	12.2	12.8			12.6
Caudal posterior margin	20.4		21.2	23.1	26.9	
First dorsal length (D1L)	20.7	22.6	22.2			23.2
First dorsal anterior margin (D1A)	28.2	27.1	29.1			
First dorsal base (D1B)	15.7	16.9	18.7	13.7	17.6	18.9
First dorsal height (D1H)	17.2	21.3		14.9	18.2	16.2
First dorsal inner margin (D1I)	5	5.1	3.5			
First dorsal posterior margin (D1P)	18.2	19.9				15
Second dorsal length (D2L)	14.3	16.9	15.4			14.8
Second dorsal anterior margin (D2A)	18.3		19.2			
Second dorsal base (D2B)	10.3	12.9	11.5	11	10.1	12.6
Second dorsal height (D2H)	16.3			13.4	12.6	14.6
Second dorsal inner margin (D2I)	4.5	4.2	3.8			
Second dorsal posterior margin (D2P)	13.8		13.5			14.4
Pelvic length (P2L)	12.4	11.1				11.4
Pelvic anterior margin (P2A)	13.2	12.2	10.6			9.9
Pelvic base (P2B)	11.8	6.4	7.1			6.3
Pelvic height (P2H)	7.7	11.7			11.6	
Pelvic inner margin length (P2I)	1.4	6				1.4
Pelvic posterior margin length (P2P)	7.7	8.7	12.2			
Trunk height (TRH)		14.2		11	18.5	14.4
Caudal peduncle height (CPH)	4.4	5.3				
Mouth width (MOW)	5.6	5.1	3.8	4.2		5.4
Nostril width (NOW)	3	1.6	2.3			
Internarinal space (INW)	1.4	2.4	1	0.6		1.3
Clasper outer length (CLO)	3.4	2				
Clasper base width (CLB)	1.3	0.9				
Spiracle length (SPL)	1.4	1.6	0.9			2.2
Eye-spiracle space (ESL)	1.9	1.6				
Trunk width (TRW)				16.1		14.4

A secondary median cusp appears posteriorly to the main one (Fig. 2A). Denticle width is 1.1-1.3 mm on the dorsal surface, decreasing ventrally to 0.7-1.0 mm (Fig. 2B). Smaller denticles are also found on the snout, caudal peduncle and fins (0.6-0.8 mm on Fig. 2C), but lacking the secondary median cusp. The minute denticles (0.3-0.4 mm) of the fin margins are monocuspid, with reduced lateral ridges (Fig. 2D). No denticles were found in the oral cavity. The claspers have monocuspid denticles with well-developed lateral wings, which give the crown a lanceolate outline. The free extremity of the clasper is scaleless. The dermal denticles of *O. paradoxus* were found to differ from the ones of *O. centrina* in the following aspects: (i) they are smaller (1.3 to 1.5 mm) on the ventral region in *O. centrina* (Reif, 1985, Plt. 9) *versus* 0.9 to 1.2 mm in the same region of *O. paradoxus*, (ii) the crown of the head scales (Fig. 2F) does not have the numerous ridges pictured by Reif (1985, Plt. 9); (iii) the scales of the anterior edge of the dorsal fin (Fig. 2E) and the supraocular ridge are similar to the ones found on the body, whereas in *O. centrina* they have very strong lateral wings and weakly developed cusps (Reif, 1985, Plt. 9); (iv) scales from the trailing edge of the pectoral fin are mostly monocuspid (Fig. 2D), whereas they are tricuspid in *O. centrina* (Reif, 1985, Plt. 9). In addition, there is a progressive reduction of the lateral wings towards the tip of the fin, where scales are needle shaped. This is also true for the other fins.

DISCUSSION

Reif (1985) differentiated sharks in six ecological groups, and stated the main role of the denticles in each one. *O. centrina* is placed in Group D (demersal sharks on sandy or muddy substrates), in which the function of squamation is protection against abrasion and ectoparasites. The same should apply to *O. paradoxus*.

Previous authors (Frade, 1932; Stephen, 1933; Cadenat and Blache, 1981) have stated that denticles of *O. paradoxus* are larger than those of *O. centrina*, giving its skin a rougher touch. The present results seem to contradict this observation. However, a larger sample of measurements on *O. centrina* is needed to confirm this. In any case, it is not clear if there is any ecological significance to larger scales. Friction drag reduction is an unlikely cause, given their presumably slow speed (Reif, 1985). Differences in scale size within this ecological group have also been noted by Muñoz-Chápuli (1985), but no inferences were made from this.

The occurrence of *O. paradoxus* in the Mid-Atlantic Ridge represents an important westward extension of the previously known geographical range of this species. It may also be an indication that it occurs deeper than the capture records suggest, with a continuous distribution across the north Atlantic from the European continental slope. If, however, a migration to shallow waters is necessary for reproduction, the distribution may be discontinuous. The population on the Mid-Atlantic Ridge could then be isolated, or connected to Europe only at its northern end.

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